(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 451 943 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 91301839.6

(51) Int. Cl.[5]: H01J 37/32

(22) Date of filing: 06.03.91

(30) Priority: 10.04.90 JP 93309/90

(43) Date of publication of application: 16.10.91 Bulletin 91/42

(84) Designated Contracting States: DE FR GB

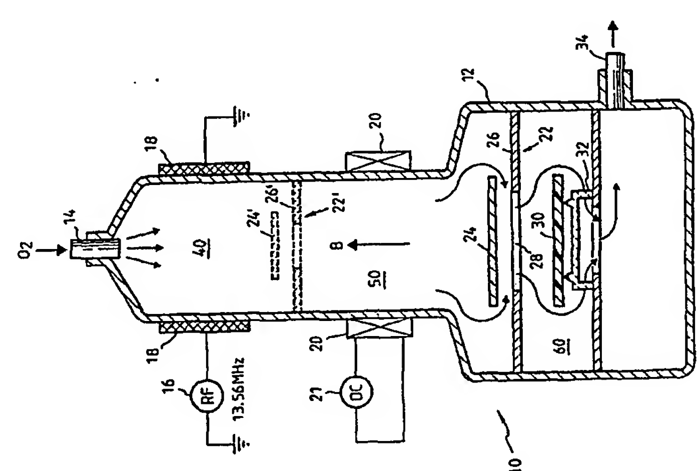
(71) Applicant: **International Business Machines Corporation**
Old Orchard Road
Armonk, N.Y. 10504(US)

(72) Inventor: **Saitoh, Takaki**
Residencenakagawa 404, 1-9-7, Ohgaya
Ohtsu-shi, Shiga-ken(JP)
Inventor: **Masuyama, Akira**
Taniguchimansion 402, 2-6 Kusatsu 3-chome
Kusatsu-shi, Shiga-ken(JP)

(74) Representative: **Burt, Roger James, Dr. et al**
IBM United Kingdom Limited Intellectual Property Department Hursley Park
Winchester Hampshire SO21 2JN(GB)

(54) Plasma processing method and apparatus.

(57) A plasma processing method for use with plasma processing apparatus (10), comprises the steps of generating plasma containing electrically-neutral reaction species in a plasma generating area (40) and processing a workpiece (30) by said reaction species in a processing area (60). The method further comprises generating a mirror magnetic field between said plasma generating area (40) and said processing area (60) so as to restrict charged particles from moving from said plasma generating area (40) to said processing area (60).



EP 0 451 943 A2

The present invention relates to a plasma processing method and apparatus, and more particularly to a plasma processing method and apparatus suited to ash the photoresist on a semiconductor wafer.

A photoresist coating on a semiconductor wafer cannot generally be removed by wet etching after the wafer is subjected to an etching or ion-implantation process. Therefore, in general, plasma ashing is used to remove the photoresist. Photoresist ashing is typically performed by oxygen plasma. In oxygen plasma ashing, primarily atomic oxygen O works as a chemically-active reaction species and reacts with the photoresist to decompose and remove the photoresist.

However, the oxygen plasma includes not only electrically-neutral plasma species such as atomic oxygen and excited state oxygen, but also charged particles consisting of positive and negative oxygen ions and electrons. These charged particles cause various problems during ashing.

One such problem is due to the bombardment by ions in the plasma. Photoresist normally contains impurities which include ions of alkali metals such as sodium and potassium and ions of heavy metals such as iron and nickel, which are mixed during manufacture of the photoresist. These impurities adhere to the surface of the oxide film under the resist during ashing. The adhered impurities are knocked into the oxide film by the bombardment of ions accelerated in the plasma, causing the characteristics of semiconductor devices on the wafer to be degraded. Plasma ions also bombard the inner wall and a sealed portion of a plasma processing chamber, causing impurities to be produced by sputtering.

Another problem is caused by electrons in the plasma. If an electric field is generated across an insulating thin film such as gate oxide due to electrons which are attached to the substrate surface during ashing, dielectric breakdown occurs which may damage the device.

In semiconductor dynamic random access memories, such as 16M-bit single chip memories, as the demand for more compact and higher-performance devices increases, it has been found that previously charged particles can now cause negligable problems.

The above problems can occur not only in resist ashing using oxygen plasma but also in plasma processing such as ordinary plasma etching and plasma CVD (chemical vapor deposition) using electrically-neutral and chemically-active reaction species or radicals. They may occur in manufacturing not only semiconductor devices, but also other devices such as magnetic and optical disks.

Therefore, for plasma processing using electrically-neutral reaction species, it is desirable to prevent charged particles from flowing to the workpiece and to supply only neutral reaction species effective for plasma processing to the workpiece.

Japanese Published Unexamined Patent Application (JPUPA) 58-91173 discloses apparatus for diagnosing radicals by blocking ions with an ion repeller to extract only neutral radicals in plasma. The ion repeller is a grid or mesh installed in the plasma chamber. Because both positive and negative ions are included in plasma, both positive- and negative-voltage repellers need to be provided in the plasma processing apparatus to repel both kinds of ions. In this case, however, the positive-voltage repeller is sputtered by negative ions and the negative-voltage repeller by positive ions, causing the problem of contamination. Though one repeller at ground potential may be used, the problem of contamination due to sputtering still occurs. In fact, it has been found that charged particles pass through the mesh.

JPUPA 62-179728 discloses a resist ashing apparatus to separate electrons and ions with a magnet and send only active oxygen to the reaction area. The magnet is arranged so that magnetic line of force generated by the magnet is perpendicular to the gas flow to deflect charged particles with the action of the magnetic field, thereby preventing charged particles from reaching a workpiece. However, this method is not preferable because contamination may occur when deflected ions collide with the inner wall of the processing chamber, furthermore ions reflected from the chamber wall may bombard the workpiece.

An aim of the present invention is to provide a plasma processing method and apparatus capable of solving the problems caused by charged particles in plasma.

In accordance with the present invention, there is now provided a plasma processing method comprising the steps of generating plasma containing electrically-neutral reaction species in a plasma generating area, and processing a workpiece by said reaction species in a processing area; characterised in that the method further comprises generating a mirror magnetic field between said plasma generating area and said processing area so as to restrict charged particles from moving from said plasma generating area to said processing area.

This has an advantage in that it substantially prevents, with a simple configuration, charged particles emitted from a plasma generating area from reaching a workpiece. Therefore, the present invention is very effective in protecting a workpiece from contamination and damage due to charged particles during plasma processing period. Moreover, since the problems caused by charged particles can be prevented even for a high plasma density, great quantities of electrically-neutral reaction species can be supplied to the processing area by increasing the processing-gas pressure and, thus, plasma processing efficiency can be

improved.

A preferred embodiment of the pres nt invention generates a mirror magnetic field between the plasma generating area and processing area to prevent the charged particles in th plasma from moving from the plasma generating area to the processing area. The mirror magnetic field is preferably generated by a coil, in parallel with the direction of gas flow from the plasma generating area to the processing area. A baffle is preferably provided between the mirror magnetic field area and the workpiece and/or plasma generating area to at least partly interrupt charged particles, and thus more effectively prevent charged particles from flowing to the workpiece.

A preferred embodiment of the present invention will now be described, with reference to the accompanying drawing which shows a schematic of the plasma processing apparatus according to this invention.

The drawing shows an example of downstream-type plasma processing apparatus 10 incorporating the present invention. In this embodiment, the photoresist on a semiconductor wafer 30 is ashed by oxygen plasma. The plasma processing chamber 12 consists of a vessel made of quartz or alumina. Oxygen gas passes into chamber 12 through inlet duct 14 at the top of the chamber and is exhausted through outlet duct 34 at the bottom of chamber 12. Chamber 12 is initially evacuated to about 10-6 torr, and then oxygen gas is introduced to a processing pressure of, for example, 4.5 torr. The oxygen-gas flow rate is, for example, 4,000 SCCM.

Oxygen plasma is generated in plasma generating area 40 by applying RF (radio frequency) power to the electrodes 18 installed at the top of chamber 12 from 13.56 MHz radio frequency power supply 16. The RF power used is, for example, 700W.

Semiconductor wafer 30, which is the workpiece to be processed with plasma, is held on support 32 installed in processing area 60 of chamber 12. Wafer 30 is covered with a photoresist layer which should be removed through plasma ashing. Wafer 30 is heated to 250°C, for example, by a halogen lamp (not shown) during ashing.

Coil 20 is installed in mirror magnetic field generating area 50 between plasma generating area 40 and processing area to generate a mirror magnetic field according to the present invention. Coil 20 is energized by DC power supply 21 to generate in area 50 a mirror magnetic field parallel to the direction of gas flow from the top to the bottom. In this example, magnetic-field direction B is upwardly directed in Figure 1. However, in other examples of the present invention, it may be downwardly directed.

Baffle 22, consisting of baffle members 24 and 26, is installed between mirror magnetic field generating area 50 and semiconductor wafer 30. Baffle member 26 has circular opening 28 with a diameter smaller than that of wafer 30 at its center. Baffle member 24 has a diameter approximately equal to that of wafer 30, which is installed immediately above opening 28 of baffle member 26 spaced therefrom. The illustrated plasma processing apparatus 10 is the downstream type in which the gas in chamber 12 flows downwardly from inlet duct 14, enters processing area 60 through baffle 22 along the arrows shown in Figure 1, advances to the bottom of chamber 12, and is exhausted from outlet duct 34.

Oxygen led in from inlet duct 14 is ionized by the RF power applied to electrodes 18 to generate oxygen plasma. The plasma includes not only neutral plasma species of atomic and excited oxygen, but also charged plasma species of positive and negative ions and electrons. Charged particles are accelerated in the plasma generation process and move at a high speed. However, the charged particles moving toward processing area 60 are reflected by the mirror magnetic field generated in area 50 by coil 20 and returned to plasma area 40.

That is, coil 20 generates a funnel-shaped magnetic field distribution in which magnetic line of force converges at the position of coil 20 and spreads toward plasma generating area 40. The magnetic field intensity is highest maximized at the convergence position which functions as a magnetic mirror. When charged particles approach the magnetic mirror from plasma generating area 40, the spiral angle of cyclotron motion changes and the particles are returned by the repulsive force of the magnetic mirror. This phenomenon is generally known as the magnetic mirror effect in high-temperature nuclear-fusion plasma confinement theory. However, as far as is known, it has not been proposed thus far to restrict charged particles from reaching a workpiece by applying the above theory to a plasma processing apparatus to generate a mirror magnetic field between the plasma generating area and processing area.

The magnetic mirror effect is effective for both ions and electrons, with only the difference that the direction of cyclotron motion of ions is opposite to that of electrons. The mirror magnetic field has only to be parallel with the gas flow and the magnetic field direction may be downward. In this case, the direction of the cyclotron motion of ions and electrons will only be reversed.

The intensity of the magnetic field needed to give the magnetic mirror effect depends on the angle between the vertical direction, or the direction connecting inlet duct 14 and semiconductor wafer 30, and the

charged-particle moving direction. Charged particles moving at large angles with respect to the vertical direction show the magnetic mirror effect with a small magnetic field. To the contrary, to provide a similar magnetic mirror effect to charged particles moving at small angles to the vertical direction, a large magnetic field is necessary. To prevent charged particles from reaching a wafer, it is preferable to reflect as many charged particles as possible with the mirror magnetic field. However, to reflect charged particles moving at an angle of 1° to the vertical direction, a magnetic field of about 1,000 G is necessary. Therefore, this enlarges the apparatus in size. The magnetic field needed to reflect charged particles which make angles of 5° to 15° to the vertical direction ranges between 10 and 100 gauss, though it depends on the shape of the plasma processing apparatus and the plasma generating conditions. Therefore, it is preferable to reflect the charged particles having a predetermined angle or greater to the vertical direction with the mirror magnetic field, and to block charged particles having smaller angles with the baffle 22.

When reflecting charged particles moving at a predetermined angle or more to the vertical direction with the mirror magnetic field, charged particles having smaller angles will pass through area 50. However, these charged particles are interrupted by baffle 22 and decelerated. Some of the decelerated charged particles are recombined, and the remaining ones may flow to processing area 60 through the gap between baffle members 24 and 26. However, since the quantity of remaining ones is extremely small and since they are also decelerated, the problem of impurity metal release mentioned above does not generally occur. Electrically-neutral plasma species are carried to processing area 60 by the gas flow and are effectively used for resist ashing.

In the drawing, baffle 22 is installed between mirror magnetic field generating area 50 and wafer 30. Instead of baffle 22, however, it is also possible to install baffle 22', consisting of baffle members 24' and 26' shown by a broken line between plasma generating area 40 and mirror magnetic field generating area 50. In this case, charged particles which make small angles to the vertical direction are interrupted by baffle 22'. As a result, only charged particles which make large angles to the vertical direction pass through baffle 22'. Therefore, this baffle arrangement makes it possible to more effectively block charged particles with less coil power. It is also possible to install both baffles 22 and 22'.

The following table shows the amount of impurity metal ions (alkali metal ions and heavy metal ions) contained in a silicon oxide layer with a thickness of 250 angstrom thermally grown on a 5-inch silicon wafer. Item (1) shows the case without ashing. Item (2) shows the case after ashing the phenol-novolac-type positive resist of 1.6 + thick, on the silicon oxide layer, without using the mirror magnetic field and baffle. Item (3) shows the case after ashing the resist only with baffle 22. Item (4) shows the case after ashing the resist with the mirror magnetic field and baffle 22 or 22'. To remove impurities or contaminants from the oxide layer surface, and measure only the impurities in the oxide layer, the wafer is washed by a heated aqueous solution of sulphuric acid and hydrogen peroxide after ashing.

Table

Case	Number of Impurity Metal Ions (ions/cm2) in Silicon Oxide Layer
1. Without ashing	0.2 x 1010
2. Ashing without the mirror magnetic field and baffle	3.7 x 1010
3. Ashing with only baffle	1.4 x 1010
4. Ashing with the mirror magnetic field and baffle	0.3 - 0.5 x 1010

When both the mirror magnetic field and the baffle are used, the contamination level can be decreased to the level when no ashing is applied, though the number of impurity metal ions in the oxide layer depends slightly on the mirror magnetic field intensity and the baffle configuration. The baffle is preferably made of quartz or alumina free from impurities, because the baffle is bombarded by charged particles.

In the example herein before described, RF power is used as the means to generate plasma. However, the present invention can also be applied to plasma processing apparatus using other well-known plasma generating means, such as 2.45 GHz microwave power and ECR (Electron Cyclotron Resonance). No matter what type of plasma generating means is used, charged particles emitted or leaked from the plasma generating area can be restricted from reaching a workpiece by generating a mirror magnetic field in parallel with the gas flow between the plasma generating area and plasma processing area. Though resist ashing using O2 plasma is shown in the above embodiment, it will be understood that the present invention can also be applied to resist ashing using a mixture gas such as (O2 + CF4), and to plasma etching and plasma CVD using electrically-neutral reaction species. Moreover, though a coil is used as the means to generate a mirror magnetic field in the embodiment, a magnet can also be used. For the baffles, various shapes and configurations can be used.

Claims

1. A plasma processing method comprising the steps of generating plasma containing electrically-neutral reaction species in a plasma generating area (40), and processing a workpiece (30) by said reaction species in a processing area (60); characterised in that the method further comprises generating a mirror magnetic field between said plasma generating area (40) and said processing area (60) so as to

restrict charged particles from moving from said plasma generating area (40) to said processing area (60).

2. A plasma processing method according to Claim 1, wherein said workpiece (30) is a semiconductor wafer having photoresist on its surface, and said processing comprises photoresist ashing.

3. A plasma processing method according to Claim 1, wherein said mirror magnetic field is generated by a coil (20) installed in an area (50) between said plasma generating area (40) and said processing area (60).

4. A plasma processing method according to Claim 1, wherein the direction of said mirror magnetic field is parallel to that of a gas flow from said plasma generating area (40) to said processing area (60).

5. A plasma processing method according to Claim 1 or 4, wherein said plasma generating area (40) is located at an upper position, said processing area (60) being located at a lower position, and the gas flow is directed downwardly.

6. A plasma processing method according to any preceding claim further including at least partly blocking charged particles by a baffle (22) installed between the mirror magnetic field generating area (50) and said processing area (60).

7. A plasma processing method according to any preceding claim further including at least partly blocking charged particles by a baffle (22') installed between the mirror magnetic field generating area (50) and the plasma generating area (60).

8. Plasma processing apparatus (10) comprising a plasma generating area (40) for generating plasma containing electrically-neutral reaction species, and a processing area (60) for processing a workpiece (30) with said reaction species, characterised in that the apparatus (10) further comprises:
mirror magnetic field generating means (20) provided between said plasma generating area (40) and said processing area (60) to restrict charged particles from moving from said plasma generating area (40) to said processing area (60).

9. Plasma processing apparatus (10) as claimed in Claim 8, wherein said workpiece (30) is a semiconductor wafer having photoresist on its surface, and said processing is photoresist ashing.

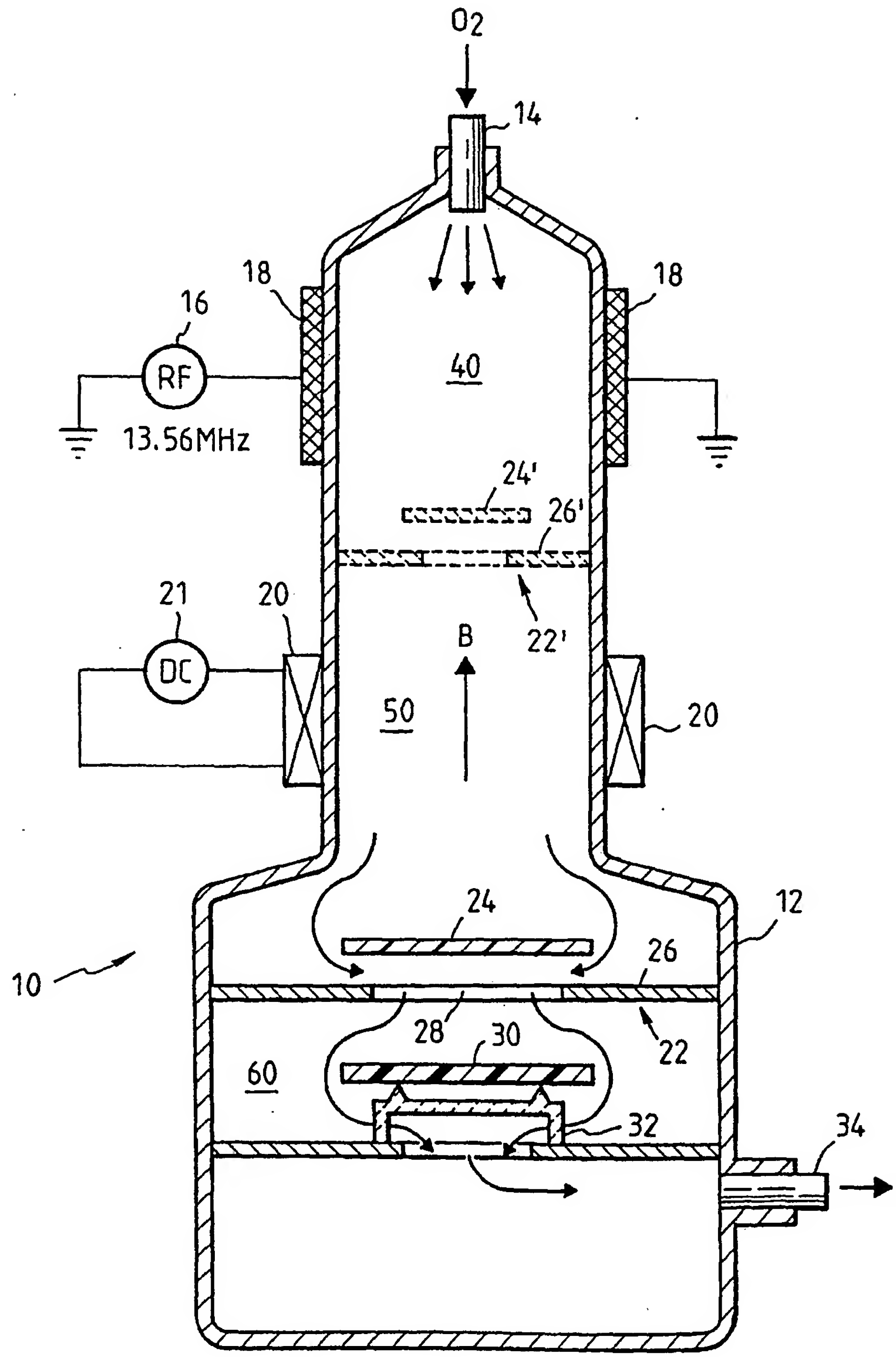
10. Plasma processing apparatus (10) as claimed in Claim 8, wherein said mirror magnetic field generating means (20) is a coil installed in an area (50) between said plasma generating area (40) and said processing area (60).

11. Plasma processing apparatus (10) as claimed in Claim 8, wherein the direction of said mirror magnetic field is parallel to that of a gas flow from said plasma generating area (40) to said processing area (60).

12. Plasma processing apparatus (10) as claimed in Claim 8 or 11, wherein said plasma generating area (40) is located at an upper position, said processing area (60) being located at a lower position, and the gas flows downward.

13. Plasma processing apparatus (10) as claimed in Claim 8, 9, 10, 11 or 12, further including a baffle (22) installed between said mirror magnetic field generating area (50) and at said processing area (60) to at least partly block charged particles.

14. Plasma processing apparatus (10) as claimed in Claim 8, 9, 10, 11, 12 or 13, further including a baffle (22') installed between said mirror magnetic field generating area (50) and said plasma generating area (40) to at least partly block charged particles.



O2
14
18
16
RF
13.56MHz
40
18
24'
26'
22'
21
20
DC
B
50
20
24
12
10
26
28
30
22
60
32
34